SHEAR STRENGTHENING OF PRE-CRACKED AND NON PRE-CRACKED REINFORCED CONCRETE CONTINUOUS BEAMS USING BI-DIRECTIONAL CFRP STRIPS

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DEDICATION

Dedicate to:

My late parents Ali bin Salleh and Yasinah binti Sinon

My dearest husband, Hasezryn bin Hashim

My siblings, nephews and nieces

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ABSTRACT

Shear failure of a reinforced concrete beam is catastrophic where it occurs suddenly and without any warning. The use of FRP sheet as a strengthening and repairing material is an effective method to enhance the shear capacity of the beam. Extensive researches have been conducted on the shear strengthening of reinforced concrete simply supported beams using FRP composites. However, strengthening continuous beams in shear have received very little attention among the researchers although most of the existing structures are in the form of continuous condition. Furthermore, there are restraints to add shear reinforcement to the existing reinforced concrete beams when beams are part of the floor-beam system. In the design guideline by ACI 440 Committee mentioned that the existing theoretical model have not been confirmed to be use for strengthening in negative moment region which existed in continuous beam. Therefore, in order to address the problem, a study on shear strengthening of reinforced concrete continuous beam using CFRP strips was conducted. An experimental work on 14 full-scale reinforced concrete continuous beams with a size of 150x350x5800mm was carried out. Simulation using finite element software ATENA v4 and theoretical analysis was also conducted. The variables involved a number of CFRP strips layers (one and two layers), wrapping schemes (four sides and three sides), orientation of CFRP strips (0/90 and 45/135 degree) and shear span to effective depth ratio, a_v/d (2.5 and 3.5). The type of FRP used was bi-directional CFRP strips. Two beams were un-strengthened and treated as the control specimens whilst the other 12 beam were wrapped with CFRP strips. From the experimental results, all beams failed in shear as expected. Beams wrapped with CFRP strips recorded shear capacity enhancement of around 10.12% to 53.74% compared to the control specimens. Beam wrapped with two layers of CFRP strips at four sides of the beam recorded the highest shear enhancement. Simulation study also showed similar behaviour in terms of shear capacity and crack patterns. Three existing theoretical models; ACI 440, Khalifa and Nanni and *fib* models were adopted for theoretical comparison of shear capacity contributed by CFRP, V_f while for shear capacity contributed by concrete, V_c and stirrups, V_s, the equation from ACI 318-08, BS8110 and EC2 was adopted. The ACI 440 model had shown the closer value with the experimental results and a modified ACI 440 model was proposed on the effective strain limit and bond-reduction coefficient.

ABSTRAK

Kegagalan ricih bagi rasuk konkrit bertetulang adalah merbahaya dimana ianya berlaku secara tiba-tiba tanpa sebarang amaran. Penggunaan FRP sebagai bahan pengukuhan dan pemulihan adalah satu kaedah yang telah diketahui efektif bagi meningkatkan kekuatan ricih rasuk tersebut. Kajian yang mendalam telah pun dilakukan ke atas pengukuhan ricih rasuk konkrit bertetulang disokong mudah. Bagaimanapun, kajian ke atas pengukuhan ricih bagi rasuk selanjar masih tidak mendapat perhatian yang meluas sedangkan kebanyakan struktur sedia ada adalah dalam bentuk selanjar. Terdapat juga halangan bagi menambah tetulang ricih pada rasuk konkrit bertetulang yang sedia ada apabila rasuk adalah sebahagian daripada sistem papak-rasuk. Di dalam garis panduan rekabentuk yang dikeluarkan oleh ACI 440 Committee memberitahu bahawa model analitikal sedia ada masih belum dipastikan bagi digunakan untuk pengukuhan rasuk dibahagian momen negatif yang mana ianya wujud pada rasuk selanjar. Oleh itu, satu kajian telahpun dijalankan terhadap pengukuhan ricih rasuk selanjar dengan menggunakan jalur-jalur CFRP. Satu kajian makmal terhadap 14 rasuk selanjar konkrit bertetulang berskala penuh dengan saiz 150x350x5800mm telahpun dijalankan beserta simulasi menggunakan perisian unsur terhingga ATENA v4 dan analisis teori. Antara pembolehubah yang terlibat ialah bilangan lapisan CFRP, skim balutan, orientasi jalur CFRP dan nisbah rentang ricih terhadap kedalaman berkesan. Dua rasuk tidak diperkukuhkan dan diambil sebagai rasuk kawalan manakala 12 rasuk yang selebihnya dibalut dengan jalur-jalur CFRP. Daripada keputusan eksperimen, semua rasuk gagal dalam ricih seperti yang telah dijangkakan. Rasuk yang diperkukuhkan dengan CFRP mencatatkan peningkatan kekuatan ricih dalam lingkungan 10.12% - 53.74%. Rasuk yang dibalut dengan dua lapis jalur CFRP mencatatkan peningkatan ricih yang tertinggi. Kajian simulasi juga menunjukkan kelakuan yang sama dari segi kekuatan ricih dan corak keretakan. Tiga model teori yang sedia ada iaitu ACI 440, Khalifa & Nanni dan *fib* digunakan untuk perbandingan secara teori bagi kapasiti ricih oleh CFRP, V_f manakala bagi kapasiti ricih oleh konkrit, V_c dan tetulang ricih, V_s, tiga persamaan daripada ACI 318-08, BS8110 dan EC2 digunakan. Model ACI 440 menunjukkan nilai teori yang lebih hampir dengan ujikaji makmal dan satu pengubahsuaian terhadap model tersebut telahpun dicadangkan ke atas had keterikan berkesan dan pembolehubah pengurangan-ikatan.

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